

NORAD CONUS Fighter Basing

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Operations Research
Capstone Project

13 April 2010

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Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 13 APR 2010		2. REPORT TYPE		3. DATES COVERED 00-00-2010 to 00-00-2010	
4. TITLE AND SUBTITLE NORAD CONUS Fighter Basing				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) USAF Academy, Operations Research Capstone Project, USAF Academy, CO, 80840				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES Military Operations Research Society (MORS), Education & Professional Development Colloquium: Operations research: A Global Solution Methodology. 14-15 Apr 2010, Fort Lee, VA.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 21	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Overview

- Client Information
- Problem Statement
- Documentation example
- Data
- Methodology
- Analysis and Way Forward

Our Client

- NORAD
 - North American Aerospace Defense Command
 - Founded May 12, 1958 as a joint effort between the US and Canada
 - Tasked with defending US and Canadian airspace
 - NORAD uses a network of satellites, ground-based radar, airborne radar and fighters to detect, intercept and engage any airborne threat to North America.
 - Our client: Mr. Peter Puhek, J84

Problem Statement

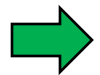
- Fighter basing optimization
 - 75 bases: AF bases, airports
 - 49 defended cities: Continental US (CONUS) state capitals & Washington DC
 - Minimize total distance from bases to cities
- Unclassified version
- Use Microsoft Office products to conduct an analysis.
 - Access database supplied by client
 - The database comes from last years project
 - Provide documentation
- Will provide a base for future projects.
- Designed to be easily modified to reflect real world situations

The Problem

- Continued from last year
- Plans to span multiple years – add more capability each year
- Excel-based solution
 - No non-Microsoft Office optimization program
 - Analysis including ALL possible solutions
 - From 1 to 75 bases utilized
 - Broader sensitivity analysis
 - Automation/integration

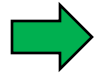
Database Documentation Example

- Visual Basic Macro code is included in the Access database
- Makes database more user-friendly
- More complete in-line comments added throughout code

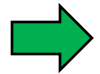


' Count selected cities.

i = 0

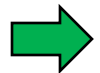


' Initializes the counter, i, for the number of cities.



If rst1.RecordCount > 0 Then

' RecordCount makes sure that the data set isn't empty.



rst1.MoveFirst

' This moves the program to the first record without applying a condition.

MainMenu_
Label

DefendedCityList_Label

Main Menu

FighterBaseList_Label

OptionsFrame_Label

Defended Cities	
CityName	CitySelected
Albany New York	Yes
Annapolis Maryland	Yes
Atlanta Georgia	Yes
Augusta Maine	Yes
Austin Texas	Yes
Baton Rouge Louisiana	Yes
Bismarck North Dakota	Yes
Boise Idaho	Yes
Boston Massachusetts	Yes
Carson City Nevada	Yes
Charleston West Virginia	Yes
Cheyenne Wyoming	Yes
Columbia South Carolina	Yes
Columbus Ohio	Yes
Concord New Hampshire	Yes
Denver Colorado	Yes
Des Moines Iowa	Yes
Dover Delaware	Yes
Frankfurt Kentucky	Yes
Harrisburg Pennsylvania	Yes
Hartford Connecticut	Yes
Helena Montana	Yes
Indianapolis Indiana	Yes

Cities selected = 49

BaseName	AirportCode	BaseSelected
Andrews AFB, MD	ADW	Yes
Atlantic City, NJ	ACY	Yes
Austin, TX	AUS	Yes
Baltimore, MD	BWI	Yes
Barksdale AFB, LA	BAD	Yes
Buckley AFB, CO	BKF	Yes
Burlington, VT	BTW	Yes
Cannon AFB, NM	CVS	Yes
Charlotte, NC	CLT	Yes
Cheyenne, WY	CYS	Yes
Chicago, IL	ORD	Yes
Columbus AFB, MS	CBM	Yes
Columbus, OH	CMH	Yes
Corpus Christi NAS, TX	NGP	Yes
Dallas, TX	DFW	Yes
Davis-Monthan AFB, AZ	DMA	Yes
Des Moines, IA	DSM	Yes
Detroit, MI	DTW	Yes
Dover AFB, DE	DOV	Yes
Duluth, MN	DLH	Yes
Dyess AFB, TX	DYS	Yes
Edwards AFB, CA	EDW	Yes
Eglin AFB, FL	VPS	Yes

Bases selected = 75

OPTIONS

- ☐ 1) Edit City data
- ☐ 2) Edit Fighter Base data
- ☐ 3) Load City data from Excel
- ☐ 4) Load Fighter data from Excel
- ☐ 5) Export ALL data to Excel

EditCity_Option

EditFighterBase_
Option

LoadCity_Option

LoadFighterBase_O

~~ExportAll_Option~~

FighterBaseList



EditCity_Label

EditFighterBase_Label

LoadCity_Label

LoadFighterBase_Label

ExportAll_Label

CloseDataBase

DefendedC

ityList

BasesSelectedCo	unt	Label
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BasesSelectedC
ount

label	CitiesSelectedCount_L	CitiesSelectedCount_C
0	1	1
1	1	1
2	1	1
3	1	1
4	1	1
5	1	1
6	1	1
7	1	1
8	1	1
9	1	1
10	1	1
11	1	1
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1
17	1	1
18	1	1
19	1	1
20	1	1
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89	1	1
90	1	1
91	1	1
92	1	1
93	1	1
94	1	1
95	1	1
96	1	1
97	1	1
98	1	1
99	1	1

CitiesSelectedCount

Data Collection and Manipulation

- Data Provided by Client
 - Latitude & Longitude of 49 cities and 75 bases
 - Verified using an Atlas
 - Small degree of error (center of city/base)
 - Makes of difference of 5-10 miles
 - < 1% of most pairs
- Spherical geometry calculates the distance
 - Assumes ellipsoid for these equations
 - Check Excel formulation vs. Vincenty equation
- Verification using 30 sample base/city pairs.
 - If significantly different, Team will reevaluate excel implementation of formula

Vincenty Equations

$$\alpha_1 = \arctan \left(\frac{\cos U_2 \sin \lambda}{\cos U_1 \sin U_2 - \sin U_1 \cos U_2 \cos \lambda} \right)$$

$$\alpha_2 = \arctan \left(\frac{\cos U_1 \sin \lambda}{-\sin U_1 \cos U_2 + \cos U_1 \sin U_2 \cos \lambda} \right)$$

Alpha- Azimuth

U- Reduced latitudes

Lambda- differences in longitude

Reduction in Bases

- Objective Criteria
 - Runway length
 - Residential areas nearby
- Subjective Criteria
 - Infrastructure
 - Terminals, nearby roads
 - Proximity to capitol cities and other important targets

Line

Path

Length: 6,936.49 Feet

Heading: 135.06 degrees

☒ Mouse Navigation

Clear

Naval Air Station Corpus Christi

3216 ft

© 2010 Google
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Image Texas General Land Office

Imagery Date: Dec 31, 2008

27°41'10.42" N 97°17'06.82" W elev 15 ft

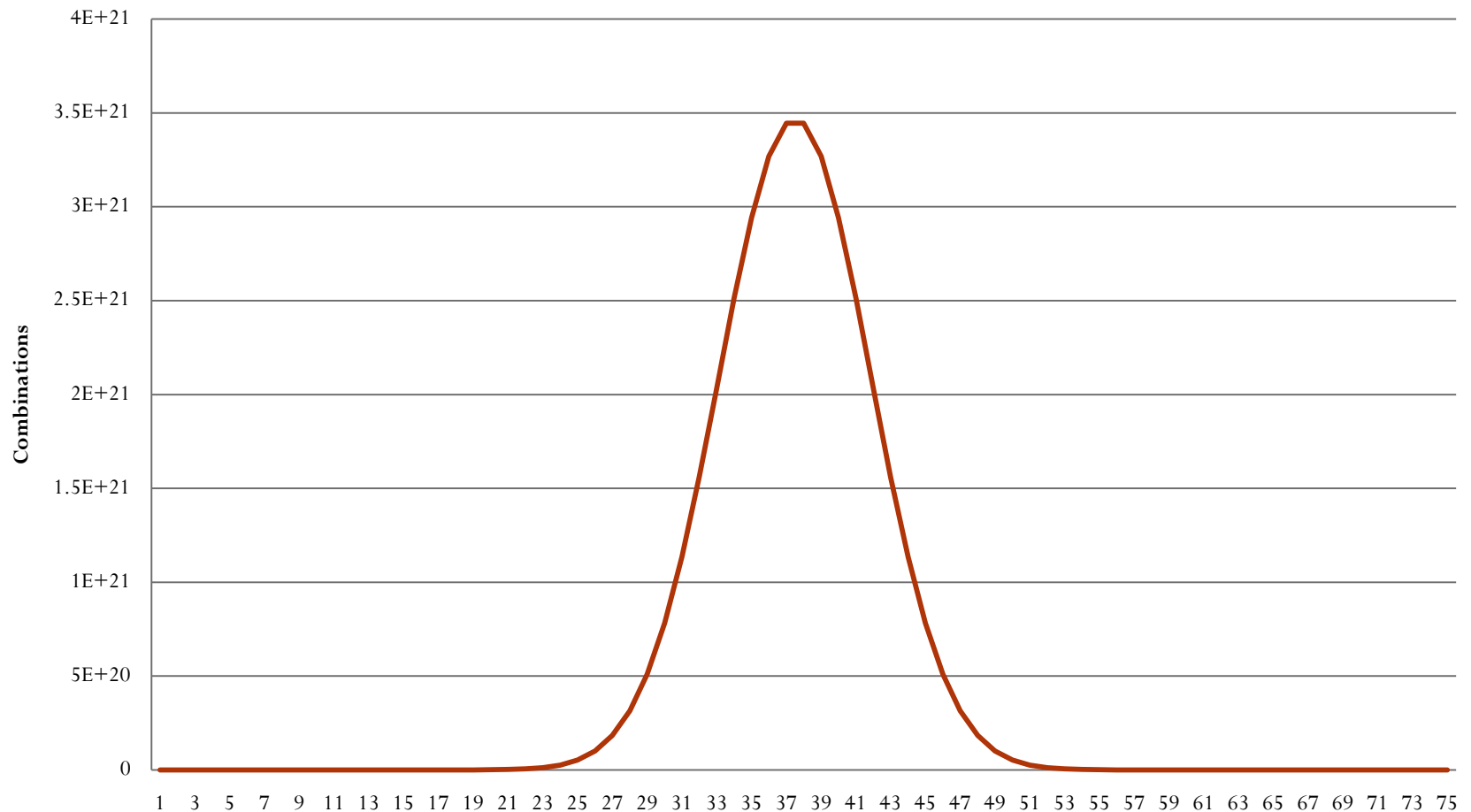
Eye alt 11114 ft

Methodology – Initial Attempt

- The initial plan included a solution algorithm based on full enumeration
- After implementing an Excel Macro to solve for the 2-base solution, we began to suspect a problem (20+ min solution time)

Methodology - Combinations

Combinations by # Bases Included



Methodology – Initial Attempt

- The maximum number of combinations exceeds $3.4 * 10^{21}$
- This would require greater than a lifetime to solve, given current computational power
- Since complete enumeration is intractable, we must reduce the solution space

Methodology - Revised

- After consulting our client, we decided to formulate the problem as an Integer Program
- We formulated an IP in Excel and used Premium Solver V9.6 to find solutions
- We thought Premium Solver would significantly reduce the solution space through branching and bounding, but it does not
- The IP is only useful when small numbers of bases are included

Methodology – IP Formulation

Distance Matrix					
	Potential Bases				
Defended Cities	1	2	3	4	5
1	866	1601	577	481	697
2	1306	281	1326	911	1822
3	722	1281	512	320	868
4	1460	312	1580	1378	2108
5	734	782	780	716	1300
6	816	2218	660	1331	192
7	779	2085	555	1136	45
8	1001	1729	705	568	719
9	809	1689	509	607	563
10	1142	588	1306	1301	1835

Methodology - IP Formulation

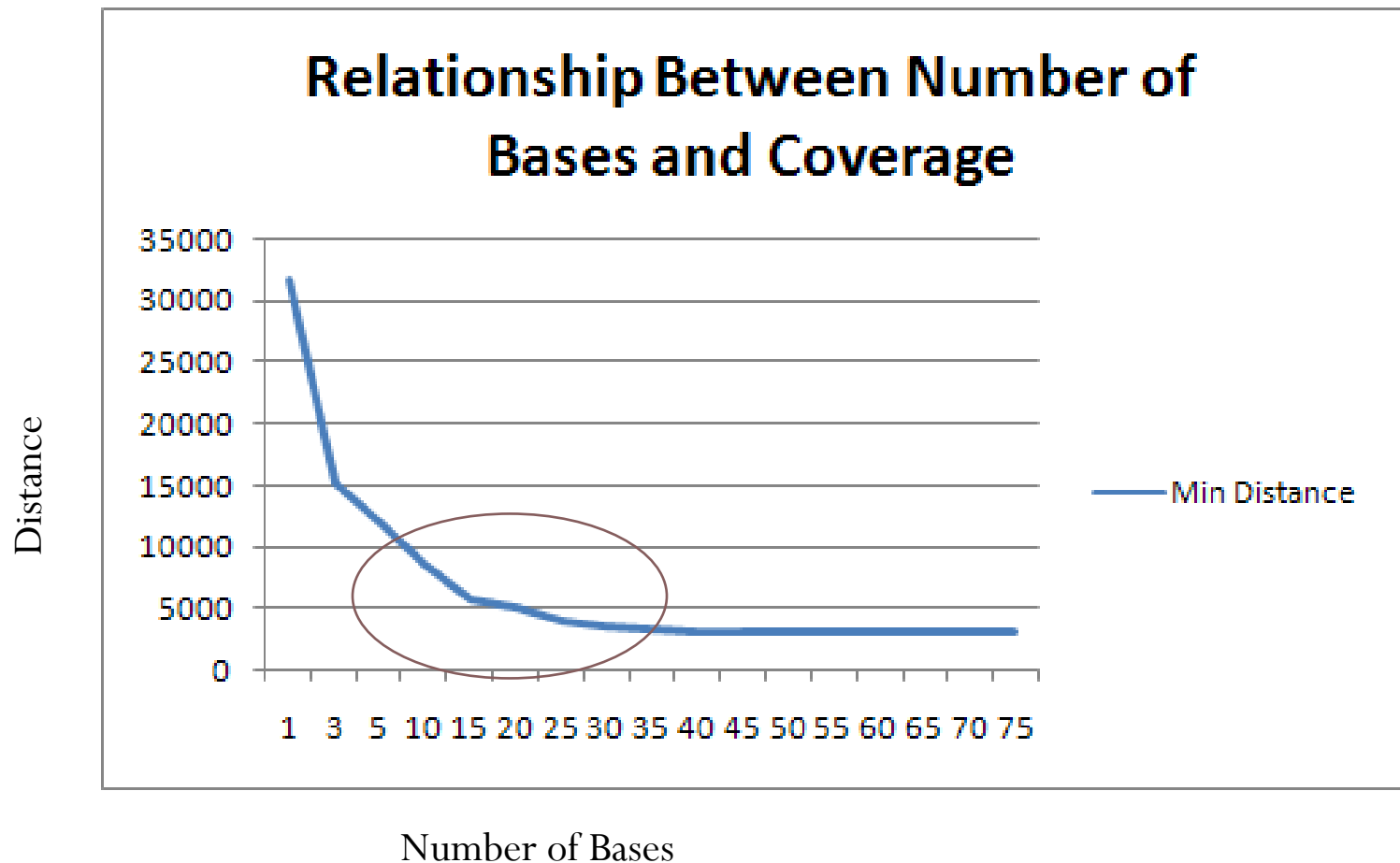
- Objective: Minimize the sum distance from each included base to each defended city.
 - The formulation sums 49 statements similar to $\text{=LARGE}(\text{distances}, \text{\#bases included})$, one for each city.
- Constraints: Number of bases included, binary variables
- Decision variables are limited to 75 by creatively utilizing an Excel function which dynamically chooses which included base defends a particular city

Methodology - Heuristics

- Since the IP has proven to take too long, heuristics must be used to make recommendations when large numbers of bases are considered
- Through analysis, we were able to determine the global optimum solution, which includes 39 bases
- Next, implement a version of the Greedy algorithm
 - Should allow a very quick; although, sub-optimal solution
 - Will operate by removing bases from the global optimum choice, while minimizing distance penalties

Analysis and Way Forward

- Searching for the “Sweet Spot” based on decreasing returns



Analysis and Way Forward

- Final recommendation will include which base choices result in good solutions
- Recommendations will be made for 1 to 75 bases utilized

Questions?